CURVATURE MEASUREMENTS OF STRESSED SURFACE-ACOUSTIC-WAVE FILTERS USING BRAGG ANGLE CONTOUR MAPPING

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ABSTRACT

Surface-acoustic-wave (SAW) transversal filters consist of piezoelectric single-crystal quartz plates (dies) with interdigital thin film transducers. The performance of these devices is critically dependent on the spacing and geometry of the interdigitation. Any manufacturing process errors that affect the geometry of the transducers and/or the surface acoustic wave speed will affect the device filter frequency. The presence of stresses or other crystalline defects in the dies can affect the SAW velocity and consequently the frequency of the SAW filter. Bragg angle contour mapping, performed with a double-crystal diffractometer, was used to determine the radii of curvature of single-crystal SAW substrates and test specimens. The angular increment and spacing between contours was then used to calculate the radius of curvature (R) from which the stress could be determined. Grit blasting of the back side of the substrates greatly increased the curvature of the dies (R < 5 m) thereby producing stresses, which could be a source of long term frequency drift as the stresses gradually relax. The adhesive used to mount the dies to a pedestal in the device package also produced deformations in the dies. Both of these effects were more pronounced with thinner substrates. Based on these observations, the grit blasting procedure was eliminated and thicker substrates were used to fabricate the SAW devices. As a result, the radii of curvature of devices manufactured under these conditions were larger (R >100 m) than could accurately be measured by the Bragg angle contour technique and the stress levels were greatly reduced.

INTRODUCTION

A typical SAW filter is constructed from a flat, piezoelectric quartz single-crystal plate (die) with two interdigital aluminum thin-film transducers on its top surface. The performance of the filter is critically dependent on the spacing and geometry of the interdigitation. Any manufacturing process errors that affect the geometry of the transducers and/or the surface acoustic wave speed will affect the device filter frequency. One area of particular concern, for both random variations and long term drift of device frequency, has been the introduction of stress into the quartz substrates. Possible sources of stress included the use of a grit blasting procedure for roughening the back surface of the SAW dies and the use of certain types of adhesives and mounting techniques for bonding the device in its package.

Double-crystal X-ray topography is an extremely sensitive technique that can detect strains at the part per million level and, as a result, it can image microscopic defects at relatively low magnification because it is sensitive to the minute but macroscopic strain fields associated with them. Equi-inclination [1-6] and Bragg angle (θ) contour mapping [4-9] are techniques which have been used to measure angular misorientation and changes in lattice parameter in single crystals. Bragg angle contour mapping can also be used to determine the radii of curvature of single-crystal
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substrates. If a sample is inhomogeneous and the range of Bragg angles is much larger than the intrinsic rocking curve width, then only those parts of the sample where the diffracting plane normals of both the sample and monochromator are coplanar, can Bragg reflect. The resulting topographic image is a single contour, which may be branched, and connects parts of the sample with the same effective Bragg angle deviation (Φ) which is given by [5]:

\[ \Phi = \Delta \theta_{\text{d-spacing}} \pm \Delta \theta_{\text{inclination}}, \]

\[ \Delta \theta_{\text{d-spacing}} = \tan \theta_B \Delta d/d, \]

\[ \Delta \theta_{\text{inclination}} = n_g \cdot n_t \Delta \theta, \]

where \( \theta_B \) is the mean Bragg angle, \( d \) is the corresponding d-spacing, \( n_g \) and \( n_t \) are unit vectors parallel with the goniometer axis and local lattice tilt axes respectively, and \( \Delta \theta \) is the angle of inclination from the mean plane. Therefore, changes in \( \Phi \) have a component that is related to differences in lattice parameter (d) and local inclination. For the quartz SAW substrates it was assumed the \( \Delta d \) is insignificant. Since the sample can easily be rotated about its surface normal and a tilt axis in the plane of incidence without changing the reflection indices, \( n_g \) and \( n_t \) can easily be altered and, as a result, there is no unique Bragg angle contour image. The orientation of the Bragg angle contours can, therefore, be varied by rotating or tilting the sample. As an example, Figure 1 shows an example of two orthogonal series of Bragg angle contours recorded from a SAW device. These are commonly called "zebra patterns". By recording such a series of Bragg angle contours at different \( \theta \) positions on the same piece of film it is possible to calculate the radius of curvature (R).

![Figure 1. Bragg angle contour topographs of SAW substrate with 40 arc sec contours aligned (a) parallel and (b) perpendicular with long axis of the sample.](image)

The radius of curvature is related to two areas on the sample producing contours by:

\[ R = \frac{S}{\omega} \]

where \( S \) is the arc length on the sample between areas producing contours and \( \omega \) is the angular increment between contours. The distance (D) between the contours on a piece of film is related to \( S \) by [8]:

\[ D = S \sin (\theta + \alpha) \]

Where \( \theta \) is the Bragg angle and \( \alpha \) is the angle the diffracting lattice planes make with the sample surface. In the case of the example in Figure 1 it would be possible to calculate a radius of curvature for both the major and minor axes of the sample.
In order to determine the effect of grit blasting, substrate thickness, and adhesive type on stress in the SAW devices, radius of curvature measurements were made on actual SAW devices and 3 in. diameter quartz wafers that had been processed under a variety of conditions. Included in the study were:

1. Measurement of the radii of curvature in wafers and SAW devices as a function of back surface preparation (grit blasting) and substrate thickness.
2. Evaluation of annealing as a method to reduce the stress introduced by grit blasting.
3. Evaluation of distortions in the SAW dies associated with different adhesives and mounting configurations.

**EXPERIMENTAL**

Samples were analyzed with copper $\text{k}_{\alpha 1}$ radiation using a computer controlled Blake double-crystal diffractometer equipped with a $<100>$ germanium crystal as a monochromator. Figure 2 illustrates the experimental setup. The Ge (422) reflection was selected to expand the size of the beam so that as large an area of the sample as possible could be imaged. A series of slits excluded the $\text{k}_{\alpha 2}$ component and defined a 1 cm x 2.5 cm monochromatic X-ray beam which impinged on the sample crystal. The quartz wafers and SAW substrates have an orientation that is an A-rotated Y-cut, where A= 36-38°. A reflection from the sample was selected such that the incident beam made a small angle (5-18°) with the sample surface and that $2\theta$ was approximately 90°. This maximized the area covered on the sample and minimized distortion in the topographic image (i.e S $\approx$ D), respectively. Actual SAW devices were mounted recessed in a small metal can which required the use of a larger incident angle (18°) and limited the area of the sample that could be covered. An image intensifier equipped with a fluorescent screen aided in the alignment of samples by allowing low-resolution real time imaging of the X-ray topograph as a function of sample tilt, rotation, and rocking motion. This greatly facilitated optimal positioning of the Bragg angle contours with respect to major axes on the sample. Rocking curves of the beam diffracted from the sample were
recorded with a scintillation counter and were used to select the Bragg angle contour interval, \( \theta \) locations, and exposure times for the topographs. For radius of curvature measurements the contour interval typically ranged from 20-50 arc seconds. Bragg angle contour maps were recorded with either Kodak Direct Exposure Film (DEF) or Ilford L-4 Nuclear Emulsion plates.

RESULTS

Several of the three inch diameter substrates had been grit blasted on one half of the back surfaces. From the rocking curve widths and the relative number and spacing of contours in the X-ray topographs (Fig. 3) it can be seen that grit blasting produced a significant curvature to the quartz substrates and that the extent of curvature increased with decreasing substrate thickness.

Figure 3. Bragg angle contour topographs showing differences in radii of curvature between non-grit blasted (top) and grit blasted (bottom) of quartz substrates. (a) 0.040-in. thick substrate, 20 arc sec contours, notice transverse seed defects visible in image. (b) 0.020-in. thick substrate, 40 arc sec contours.

Grit blasting imparts a considerable curvature (\( R = 3.5-4.5 \) m) to the 0.020-in. thick substrates beyond that which was observed for as received wafers (\( R = 30-45 \) m). By increasing the substrate thickness to 0.040 in., the radii of curvature of non-grit blasted wafers increased to greater than 70-80 m and the effect of the grit blasting was reduced (\( R = 20-21 \) m). The radii of curvature of actual SAW devices constructed from grit blasted 0.020-in. thick substrates typically ranged from about 3m to 7 m which is consistent with the measurements from full wafers of the same thickness that had been grit blasted.

Crystalline defects such as dislocations, seeds and other defects propagated from the seeds (Fig. 3a) were observed in the 3-in. diameter wafers. These defects were not observed in the quartz dies of actual SAW devices. Annealing of 0.020-in. thick grit blasted wafers at 600\(^\circ\)C for 3 hr did not have a significant effect on the radius of curvature (\( R = 4 \) m), but the annealing did appear to promote recrystallization which appears to have reduced the dislocation density and led to the formation of subgrains.
Based on the X-ray topography results the device fabrication techniques were modified. This included increasing the die thickness to 0.040 in. and elimination of the grit blasting procedure. The effect of greater die thickness and lack of grit blasting on the curvature of actual SAW devices can be seen in the topographs in Figure 4. The Bragg angle contours on the 0.020-in. thick/grit blasted sample are very distinct whereas on the 0.040-in. thick/non-grit blasted device they are not resolvable, even with a smaller contour interval. As a result, the curvature of actual SAW devices was greater than could be measured by the Bragg angle contour technique (~ 100m) indicating that the stresses were greatly reduced.

The effect of the polyimide adhesive used to mount 0.020-in. thick devices to nickel pedestals in the device packages can also be seen in Figure 4a where the Bragg angle contours are twisted in the vicinity of the pedestal mount. The effect of the polyimide adhesive/pedestal mount on the 0.040-in. devices was greatly reduced but slight deformations were still detectable (Fig. 4b). Previously a continuous film of RTV silicone adhesive had been used to mount dies directly to the device package without using a pedestal. This technique was later abandoned because of concerns that the devices would become contaminated as a result of outgassing from the RTV adhesive. The polyimide adhesive was selected because of its low condensable contamination properties but required the use of a small pedestal mount to reduce the surface area. This was because the high modulus of the polyimide would create stresses resulting from thermal expansion mismatch. Several samples consisting of dies mounted to device packages using the RTV mounting technique were also examined by X-ray topography in order to characterize the deformations/stresses associated with this mounting method. Figure 5 shows the topographs of two 0.020-in. thick/grit-blasted dies mounted with the polyimide/pedestal and RTV adhesives. It can be seen in Fig. 5a (as in Fig. 4a) that the Bragg angle contours are greatly distorted in the vicinity of the pedestal, whereas with the continuous RTV adhesive and no pedestal (Fig. 5b) the Bragg angle contours are relatively straight and there is no additional deformation beyond that created by the grit blasting.

![Figure 4. Bragg angle contour topographs of SAW dies mounted to nickel pedestals with polyimide adhesive (a) grit-blasted sample, 0.020 in. thick, 50 arc sec contours. (b) non grit-blasted sample, 0.040 in. thick, 20 arc sec contours.](image-url)
SUMMARY

X-ray topography techniques were used to image defects and measure the radii of curvature of as received single-crystal quartz wafers and actual SAW devices. Dislocations and large scale defects, such as seeds, bubbles and subgrains were easily recognized in topographs of substandard quality quartz wafers but were not observed in actual SAW devices. Grit blasting of the backside of the wafers greatly increased the curvature (R <5m) of the dies, and increased the stress in the devices. The polyimide adhesive used to mount the dies to a pedestal in the device package also produced deformations in 0.020-in. thick dies. Both these effects were lessened by increasing the thickness of the substrates. Based on these observations, the grit blasting procedure was eliminated and thicker substrates were used in the production of SAW devices. As a result, the radii of curvature of devices manufactured under these conditions were larger than could be accurately measured with the Bragg angle contour measurement technique (R >100 m) and the stress levels were greatly reduced.

REFERENCES